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No. 242

FACTORS OF SAFETY.

By Edward P. Warner,
Professor of Aeronautics,
Massachusetts Institute of Technology.

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

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FACTORS OF SAFETY

By Edward P. Warner.

It is an unfortunate fact, which has led to a great deal of confusion in the past, that the term "factor of safety," an expression familiar to every engineer who has to discuss the strength of structures, has acquired a wholly new and misleading significance in aeronautics.

The factor of safety, as the bridge builder or the engineer responsible for the planning of a building knows it, is the ratio between the true strength of his structure and the worst load which can be foreseen as ever likely to fall upon it. If past experience suggests that the worst storms which come to Boston in the winter months will leave a maximum of 10 pounds of snow on every square foot of roof, the calculations of the strength and size of all the members which support that roof may be made as though the load to be sustained were 50 pounds on each unit area instead of 10, and the true factor of safety will then be five. Five, incidentally, is a reasonable value for the factor in buildings and other similar structures, where durability is of more importance than weight.

Three Purposes.

Such a factor serves three purposes: It provides, first

* Taken from Christian Science Monitor

of all, against trouble arising from unexpectedly large loads or from inaccuracies in the method of calculation. The theory of structural stresses is not yet an exact science when highly complex assemblies are being dealt with, and loads are often hard to determine with accuracy. After centuries of experience and with all the resources which modern research can put at their command, engineers are still discussing the allowance which should be made for wind pressure against bridges under various conditions, and there is even more uncertainty as to the effect of impact and vibration when a train passes at high speed along a rough section of track on a trestle. It is because of these uncertainties that the factor of safety is sometimes sardonically described as the factor of ignorance, the element introduced in the calculations to save the designer from the effect of the incompleteness of his own knowledge.

Second of its three excuses for being, the factor of safety serves to allow for imperfections of workmanship. The most thoroughgoing inspection cannot catch every defective rivet, and if calculation were based on a uniformly high standard the necessity of reaching that standard would exact a much higher quality of labor and inspection, and correspondingly higher labor cost, than now prevail. The introduction of a little leeway permits the use of ordinary methods, even though a certain proportion of the joints in the structure are liable to be below the quality which would be considered as standard for test purposes

This allowance for imperfections extends all the way back into the process of working the raw material, and the factor of safety covers, among other things, any departure of a part of the steel from the specified strength and properties, as well as any hidden flaw which may be the source of hidden and unsuspected weakness.

Finally, and perhaps most important of all, the factor of safety represents a depreciation allowance. A structure barely strong enough when first built would be insufficiently strong after a very short life, while one that has a reserve of 200 or 300 per cent to draw upon will last for many years.

In the Airplane.

All of these allowances must be made in the airplane quite as in the steel-framed building. The loads on the airplane are inexactly known, and the methods of stress analysis used are not rigorously accurate, since the structures are very complex. The materials and the workmanship are both liable to slight variations of quality, although the inspection is very careful at all stages and all the labor is highly skilled, and the materials used are peculiarly subject to rapid deterioration. A factor of safety is therefore needed, but the necessity of saving weight in the structure forbids that it shall be as large as in stationary structures. Careful maintenance has to replace the initial provision of a great excess of strength.

There is, to be sure, a widespread impression that the factors of safety in airplanes are higher than in buildings, running up to six and even eight, but that is based on the misunderstanding already alluded to. The "factor of safety" in aeronautical engineering has unfortunately often been defined as the ratio of the strength of the structure to the load which it carries under normal conditions, in steady flight in a straight line, and that is quite a different thing from the correct definition already given. If the "factor of safety," as defined in the preceding sentence (more correctly called the load factor), is eight, and if the worst actual load which seems likely to fall on the structure in flight is four times the load sustained when traveling normally on a straight and horizontal course, the real factor of safety is only two, and that is about the customary value, both for airplanes and for airships, although the determination of the true factor for airships is considerably hindered by the almost complete lack of knowledge which prevailed, until a few months ago, with regard to the loads when maneuvering.

In Maneuvers.

Direct calculation, wind tunnel tests and actual measurements in flight agree in showing that the load on the wings of an airplane in certain maneuvers is much higher than in normal flight. The reason is evident. If a weight is swung around at the end of a string there is a continuous pull in the string, and the pull increases as the weight is swung more and more rap-

idly. In exactly the same way, an airplane describing a loop, for example, tends to pull away from the center about which it is turning and, since there is no string to guide it, the force needed to hold the airplane to its curved path must be furnished by the lift on the wings. It is common to get a total lift as great as three times the weight of the airplane and its contents, and the ratio may even rise to a little over four in executing a barrel roll, pulling out of a steep dive rapidly or making a very sharp turn at high speed. The load on the wings in normal straight flight is, of course, equal to the weight. The loads can readily be calculated if the nature of the motion in the maneuver is known, and it can be shown, for example, that a racing airplane making a turn at four miles a minute would carry on its wings a load equal to four times its own weight if the diameter of the circle on which the turn was made were 2000 feet. It would be quite impossible to turn very much shorter than that, although the witness of such a contest as the Pulitzer race gains an exaggerated idea of the quickness with which the competing airplanes swing about.

Since not all airplanes are designed for the same service, the same load factor is not used in all cases. Training airplanes and those for combat, which must be stunted violently and which may therefore carry loads as great as four times their weight, are designed with a load factor of eight. Large commercial airplanes, on the other hand, are turned only with compara-

tive gentleness, and it is unlikely that the true load on the wings will ever exceed double the weight. The ratio used in calculating the strengths of the parts is therefore taken as four, which gives just the same true factor of safety as the higher figure adopted for the smaller and livelier airplanes.